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Pricing of Thermal Energy for Direct Use Applications

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ABSTRACT

Energy from geothermal resources can either be electrical or thermal. Kenya has been generating geothermal electrical energy for over thirty years but the use of thermal energy is not well developed. As a result, a tool for determining the price of electrical energy was developed and is in use by the Energy Regulatory Commission to set the electricity tariff. Thermal energy for direct use applications is still a relatively new technology in Kenya and pricing of the same has not been developed.

The Kenyan government plans to establish Geo-Industrial Parks close to the geothermal fields to utilise thermal and electical energy as well as other geothermal by-products. Thermal energy from the fields will be supplied to industries as an alternative to fossil fuels. Therefore, the thermal energy should be priced so that it is competitive against the fossil fuels while at the same time ensuring the developers do not operate at a loss.

The objective of this paper is to provide a guide for determining a tariff for thermal energy from a geothermal resource. The energy will be used to meet the process heat needs of industries in an industrial park setting. Two methods of setting the price for the thermal energy are proposed: Cost-plus pricing and pricing relative to the cost of competing alternatives fuels. (Friðriksson, 2016).

To demonstrate the application of the two methods in determining the thermal tariff, analysis of two (2) possible sources of thermal energy in Menengai geothermal field was carried out. These include a low pressure geothermal well and separated brine from a geothermal power plant.

Since water is the carrying medium for the thermal energy, a suitable tariff for the hot water was determined to have a floor of 1.72 and 3.93 $/m^3 and a ceiling of 11.15 and 13.24 $/m^3 depending on source of thermal energy. The floor price is equivalent to the tariff at which the hot water should be priced to just cover all the operating expenses while the ceiling price is the price of hot water equivalent to the price of conventional sources of thermal energy for industrial applications.

1. Introduction

Direct use of geothermal energy is set to be the next frontier for growth in geothermal energy utilization. The Global Geothermal Alliance is aspiring to achieve a twofold growth in geothermal direct use by 2030 (Global Geothermal Alliance, 2017).

Kenya has made strides towards the development of direct use with the development of a direct use guidebook. The guidebook identifies the possible direct use investment opportunities in various geothermal fields in Kenya, and ranks them in a prioritized order based on a set of criteria.

A direct use demonstration project was commissioned in Menengai geothermal field in 2015 to create awareness on the possibilities of direct use investment. The demonstration project comprises of a geothermal heated greenhouse, geothermal heated aquaculture pond, a milk pasteurizer and a laundry unit (Mburu, 2015). Furthermore, direct use applications at a commercial scale are installed in Oserian for greenhouses heating; and Olkaria and Lake Bogoria spa. Small scale direct use community projects are also installed at Eburru for crop drying and at Suswa. These direct use projects have an estimated installed capacity of 22.4 MWt (Omenda & Simiyu, 2015).

The Kenyan geothermal developers are taking steps to develop direct use of geothermal energy for commercial purposes. The target customers for the geothermal heat are mainly agricultural and industrial consumers of low grade heat, who currently use fossil based fuels for their process heat requirements. These fossil fuels, mostly imported, are sources of pollution and greenhouse gases. In addition, they are relatively expensive. On the other hand, geothermal produces less pollutants and greenhouse gases.

The Energy Regulatory Commission is mandated to set the tariff for electricity in Kenya. The tariff is reviewed regularly to ensure that it captures the prevailing economic conditions (Regulus, 2014).While it argued that geothermal is a cheaper source of process heat in comparison to fossil fuels, a similar process for setting the tariff for thermal energy for direct use applications is nonexistent in Kenya. It is therefore challenging to compare the economics of using geothermal energy versus fossil fuels to provide process heat for direct use applications.

A review of literature reveals that the largest portion of energy supplied to consumers world over is in the form of heat; either for spacing heating or process heating. The pricing models for this form of energy varies greatly from place to place. There is little transparency in the pricing models used by the suppliers of heat because most of the suppliers are monopolies in their areas of operation as is the case with district heating systems. Consequently, there is very little information is available on pricing models for thermal energy. However, the two main models used to price thermal energy are as follows (Gidlof, Hasselberg, & Kylberg, 2015)

a. Dynamic pricing model – in this model the price varies depending on the energy or hot water consumed by the customer.
b. linear pricing model – in this model, also known as fixed charge model,
c. Dynamic and fixed pricing model – this model has a dynamic component and a fixed charge based on previous year's consumption.

The strategies that are employed by the thermal energy suppliers in coming up with the pricing models are as follows (Skjæveland, 2016)

a. Cost plus pricing strategy – this takes into account the cost incurred to generate heat during a given period of time plus a markup, calculated as a percentage of the incurred cost.
b. Marginal cost pricing strategy – this is the cost of generating an additional unit of heat expressed in kWh.

This paper describes the process of establishing the price of thermal energy and compares it to the price of conventional energy sources for industrial process heat. The scope of the paper entails the various sources of thermal energy in Menengai geothermal field, analysis of the energy that can be obtained from those sources, determining the cost of delivering the energy to customers within an industrial park setting and setting a tariff for the thermal energy based on the determined costs.

2. Thermal Energy: Sources and analysis

Menengai geothermal field is used as a case study in determining the price of thermal energy. It is assumed that the energy for direct uses will be obtained from the following sources.

1. Separated brine from high enthalpy wells which will be connected to a 105 MW power plant.
2. Low pressure wells which are not suitable for electricity generation

The following assumption were made regarding the sources of thermal energy:

a. Separation of brine and steam for electricity generation is done at a pressure of 7 bar.
b. The specific steam consumption of a geothermal power plant is 8 ton/hr.
c. The dryness faction of the high enthalpy wells is 0.6.
d. The low pressure well discharge 150 ton/h of geothermal fluids at a pressure of 2.5 bar. These fluids will not be separated during utilization.

Geothermal fluids contain dissolved substances which are known to cause downstream challenges such as scaling and corrosion during utilization. To avoid this, thermal energy must be is extracted from the geothermal fluids using fresh water across a heat exchanger. During heat exchange, the saturation temperatures of the various dissolved substances should be taken into account to avoid excessive scaling at the heat exchanger. The amount of thermal energy extracted from the two sources of geothermal fluids, together with the amount of fresh water required during the heat exchange are shown in table 1.

Table 1: Energy extracted from different sources of geothermal fluids

Source of thermal energy	**Energy Available for extraction (MWt)**	**Fresh water mass flow rate (kg/s)**
Separated brine	37.5	77.5
Low pressure well	9.1	21.8

3. Thermal energy supply system

The energy extracted from the geothermal fluids requires transportation from the heat exchanger to the point of utilization. It is expected that an industrial park will be established in Menengai

geothermal field, where the users of this energy will be located. Since the carrying medium for the energy is water, a pipeline complete with associated accessories will be required to transport the energy laden water.
The major equipment required to supply the energy to the industrial park include an insulated hot water delivery pipeline, a return water pipeline, a brine reinjection pipeline, heat exchangers and pumps. The following assumptions were made in determining the required size of the energy delivery equipment.

a. A heat exchanger is used to extract energy from the geothermal fluids into fresh water.
b. All the available brine is used during heat exchange.
c. All the energy extracted from the geothermal fluids into fresh water will be utilized.
d. The geothermal fluids must be re-injected back into the ground after heat exchange.
e. The hot fresh water is cascaded through thermal processes. Some of the hot water is consumed by the thermal processes while some remains in circulation. About 40% of the water will remain in circulation and be returned to the heat exchanger for re-heating.
f. In the case where the source of energy is "separated brine", a new re-injection pipeline will not be required. This is because a re-injection pipeline for the 105MW power project already exists.
g. The hot fresh water, the return water and the brine will either be pumped or flow by gravity based on the elevations under consideration.
h. The pipeline carrying the hot fresh water must be insulated while the return water and brine re-injection pipelines are not insulated.

Based on these assumptions, the following sizes of equipment were determined as shown in table 2.

Table 2: Energy delivery equipment by size

Source of energy		**Separated brine**	**Low pressure well**
Section	Equipment	Equipment size	Equipment size
Hot water pipeline	Pipe diameter (inches)	12	6
	Insulation thickness (mm)	50	50
	Heat exchanger area (m2)	51	32
	Pump rating (kW)	0	198
Return pipeline	Pipe diameter (inches)	8	4
	Pump rating (kW)	2.05	0.86
Reinjection pipeline	Pipe diameter (inches)	16	10
	Pump rating (kW)	0	1.25

It can be observed that in the hot water pipeline, pumping is not required when the source of thermal energy is separated brine. This is because the head was assumed to be positive.

4. Costing

A project incurs various cost in the course of its set up and operation. These costs can be classified as follows:

a. Investment costs
b. Fixed costs
c. Operation costs
d. Shared costs

4.1. Investment cost

The costs incurred in the acquisition of project assets such as land, equipment, vehicles and buildings are referred to as investment/capital costs. Investment costs occur at the beginning of the project. In this project, only the cost of energy delivery equipment is considered as shown in table 3.

Table 3: Cost of energy delivery equipment

Source of energy		**Separated brine**	**Low pressure well**
Section	Equipment	Equipment cost (USD)	Equipment cost (USD)
Hot water pipeline	Pipeline	616,798	367,454
	Insulation	204,980	111,458
	Heat exchanger	22,960	16,043
	Pump	0	6,561
Return pipeline	Pipeline	419,948	209,974
	Pump	6,566	6,563
Reinjection pipeline	Pipeline	0	196,850
	Pump	0	6,564
	Total	**1,271,252**	**921,468**

4.2. Fixed costs

The costs incurred by a project during its operation. These costs do not vary with the level of production. The major fixed costs associated with this project are:

i. Financing costs - interests on any loans acquired by the project.
ii. Depreciation – the perceived loss of value of an asset caused by obsolescence, wear and tear as well as degradation due to environmental exposure.
iii. Cost of insurance.
iv. Equipment maintenance costs.
v. Salaries of administrative staff.

The assumptions used to determine the fixed costs are as follows:

1. Financing cost assumptions
    a. 80% of the investment cost is obtained from debt financing while 20% is from equity.
    b. The debt financing was obtained at an interest rate of 6%.
2. Depreciation for the various equipment is as shown in table 4.

Table 4: Rates of depreciation for assets

Annual depreciation	**Rate**
Pipeline	2.5%
Insulation	2.5%
Heat exchanger	10%
Pump	10%

3. Maintenance of equipment cost is calculated at 3% of the investment cost.
4. Average salary of administrative staff is $21,000/person/year.

4.3. Variable cost

These are operating costs that vary with the level of production. The major variable costs under consideration in the project are:

i. Variable allowances for operations staff.
ii. Cost of electricity.
iii. Cost of fresh water.

The assumption used to determine variable costs are as follows:

a) Average variable allowance for operations staff is $6,000/person/year.
b) Number of staff is eight (8).
c) The cost of electricity is $0.16/kWh.
d) The cost of fresh water is $1.3/m^3

4.4. Shared cost

In a case where the thermal energy for direct uses is obtained as a by-product of electricity generation i.e. from separated brine, then the cost of operations must be shared between the electricity generation and thermal energy generation. The shared assets include the following:

a. Geothermal wells
b. Separator stations
c. Brine reinjection pipeline

The operation costs for these assets (both fixed and variable) are shared proportionately between electricity generation and thermal energy generation. This proportion is calculated by determining the amount of energy from the wells that goes into electricity generation as well as the amount of energy that goes into thermal energy generation. This method is used in Iceland by the energy authority to separate the books of accounts for the energy companies which generate both electrical and thermal energy. This is expressed in equation 1 (Orkustofnun, 2011).

$$P_{Thermal} = \frac{1}{2} * \left[\left(\frac{x*Q}{E+(x*Q)} + \frac{x*\dot{Q}}{P+(x*\dot{Q})}\right)\right] \quad (1)$$

Where,

$P_{Thermal}$ - Proportion of the energy that is used to generate thermal energy

x – Exergy contained in a stream of water (kWh/m^3)

Q - Quantity of fresh water used during heat exchange (‘000 m^3)

E – Electrical energy generated using the shared resources in a given period (kWh)

$\dot{Q}$ – Maximum hot water flow rate (m^3/h)

P – Maximum electrical power capacity (kW)

The assumptions made in determining the $P_{Thermal}$ are as follows:

i. The electricity power plant has a capacity of 105MW and a capacity factor of 95%.
ii. The thermal power plant has a utilization capacity of 60%.
iii. The cost of drilling a geothermal well is USD 5 million.
iv. One (1) makeup well is to be drilled every 5 years

It was established that the proportion of shared cost incurred by the thermal energy generation is 4%.

5. Thermal tariff determination

The first method used to determine the tariff for thermal energy is referred to as Cost-Plus Pricing. The cost-plus pricing strategy assumes that the revenue which a business expects to generate in a particular period of operation should be able to cover all the costs incurred during the same period and comprise of the following:

a. All the operating costs incurred during that period (including the shared costs).
b. The depreciation of the assets during that period.
c. The expected profit for that period.

That relationship is illustrated in equation 2.

$$R_{expect} = OP_{Expect} + D_{expect} + P_{expect} \tag{2}$$

Where,

R_{expect} – expected revenue in a period of operation.

OP_{Expect} – expected operating expenses in a period of operation.

D_{expect} – expected depreciation of assets in a period of operation.

P_{expect} – Expected profit during a period of operation (mark-up) calculate as a percentage of expected annual revenue.

The costs that are used in the determination of the thermal tariff for the four (4) sources of thermal energy are shown in table 5.

Table 5: Tariff determination costs

Annual Depreciation	**Rate**		**Separated brine**	**Low pressure well**
Pipeline	2.5%		25,919	19,357

Insulation	2.5%	Of investment cost	5,125	2,786
Heat exchanger	10%		2,296	1,604
Pump	10%		657	1,969
Total Depreciation			**33,996**	**25,717**
Annual Fixed Costs			**Separated Brine**	**Low pressure well**
Equipment maintenance	3%	of equipment cost	38,138	27,644
Interest on loans	6%	of loan balance	61,020	44,230
Administrative salaries (USD)	21,000	per person/year	168,000	168,000
Total Fixed Costs			**267,158**	**239,874**
Annual Variable Costs			**Separated Brine**	**Low pressure well**
Electricity (USD)	0.16	USD/kWh	2,874	3,232
Water	1.30	USD/m^3	1,907,372	894,013
Operations allowances	6,000	per person/year	48,000	48,000
Total Variable Costs			**1,958,247**	**945,246**
Total Proportionate Shared Cost			263,255.64	0
			Separated Brine	**Low pressure well**
Expected Annual Revenue (USD)			**2,522,656**	**1,210,837**
Expected Annual Profit		% of expected annual revenue	-	-
Total Expected Revenue			**2,522,656**	**1,210,837**
Hot water consumption (m^3/year)			1,467,209	412,622

Price of Hot Water (USD/m3)			**1.72**	**2.93**

The tariff is expressed in terms of USD/m^3 of hot water. This is obtained by dividing the total expected revenue by the amount of water which was utilized during that period.

It can be observed that higher operating costs are incurred when separated brine is the source of energy However, the hot water generated from the energy in the low pressure well has a higher tariff that that from separated brine. This is because in the case of separated brine, more hot water is generated than in the case of the low pressure well.

5.1. Weighted price of hot water

Different thermal processes demand hot water at different temperatures. A thermal process demanding water at a high temperature should pay more for the same volume of hot water than a thermal process demanding water at a lower temperature. The differentiation in the price of hot water with respect to the temperature is based on the exergy available in the hot water at that temperature. Exergy refers to the work which can be recovered from a stream of hot water and is determined by two factors:

a) Inlet temperature – the temperature at which the hot water enters into a thermal process.
b) Outlet temperature – the temperature at which hot water exits from a thermal process.

A thermal process that demands hot water at a high temperature will have higher exergy at its disposal relative to a thermal process that demands hot water at a lower temperature. Therefore, the price that each of the thermal processes is charged for the hot water is proportional to the exergy availed to it. If a thermal process only extracts some energy from a stream of hot water and passes the remaining energy to another thermal process, it is charged in proportion to the exergy it will have extracted from the hot water as shown in table 6.

Table 6: Exergy weighted price of thermal energy

Weighted hot water prices				
Energy Source	**Separated Brine**		**Low pressure well**	
Exergy (kJ/kg)	70		53	
Temp. (°C)	Weighted price (USD/m3)	Cumulative price (USD/m3)	Weighted price (USD/m3)	Cumulative price (USD/m3)
<40	0.06	0.06	0.14	0.14
40 - 70	0.18	0.24	0.43	0.57
70 - 90	0.26	0.50	0.62	1.20
90 - 110	0.34	0.84	0.82	2.02

110 - 130	0.43	1.27	0.92	2.93
>130	0.45	1.72		
	1.72		**2.93**	

5.2. Pricing relative to the cost of alternative sources of energy

The determined price is the minimum price at which the hot water should be sold to recover the operating costs. In order to operate profitably, a markup, should be added to the minimum expected annual revenue. An appropriate level of markup should be determined so that geothermal energy remains competitive in relation to conventional sources of thermal energy. A price analysis of conventional sources of thermal energy in Kenya was carried out using the assumptions shown in table 7.

Table 7: Properties of conventional sources of energy

Fuel	Kinematic viscosity	Pour point	Sulphur content	Gross calorific value	Density (kg/m^3)	Cost
Industrial Diesel Oil (IDO)	Maximum 10 cst at 40°C	Maximum 12°C	Maximum 1.8%	Minimum 44.8 MJ/kg	960	1.15 $/litre
Heavy Fuel Oil (HFO)	Maximum 180 cst at 50°C	Maximum 27°C	Maximum 3.7%	Minimum 41 MJ/kg	990	1.00 $/litre
Dry wood				14.4-17.4 MJ/kg	370	0.2 $/m^3
Electricity						0.18 $/kWh

The analysis yielded the results shown in figure 1.

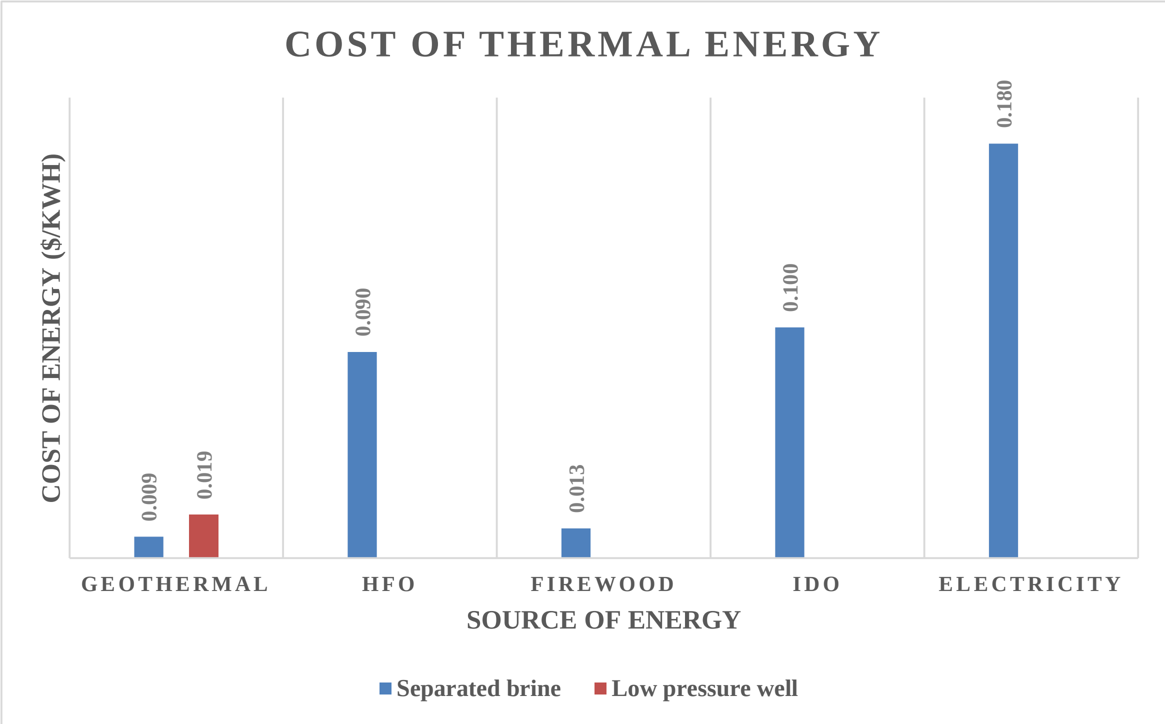

Figure 1: Comparison of the price of thermal energy from various sources

Firewood was found to be the cheapest conventional source of thermal energy while electricity was the most expensive. However, the use of firewood as a source of industrial thermal energy is considered unsustainable. As a result, most industries in Kenya use IDO and HFO to supply thermal energy.

In order for geothermal to remain competitive, its price should not exceed that of the conventional sources of energy. The cheapest conventional energy (excluding firewood) is HFO. Table 8 shows the price of hot water when no profit is factored in; when priced is at the same rate as the energy from HFO; and when priced at 75% of the price of energy from HFO.

Table 8: Price of hot water

Source of energy	Price at zero profit	Price at rate of HFO	Price at 75% rate of HFO
Separated brine	1.72	13.24	9.93
Low pressure well	2.93	11.15	8.36

As a starting point, it is proposed to price hot water at 75% the price of energy from HFO i.e. $0.054/kWh from figure 1. This price is also equivalent to 60% the price of energy from IDO.When expressed in terms of hot water, this price is equivalent to \$9.93/m^{3}and \$8.36/m^3 in the case of separated brine and low pressure well respectively.

6. Conclusion

The following conclusions can be drawn from the analysis.

a. The price of thermal energy depends on the thermodynamic characteristics of the source of geothermal fluid from which the energy is extracted.
b. At 75% the price of energy from HFO or 60% the price of energy from IDO, thermal energy from geothermal is considered competitive.
c. A combination of cost plus price and pricing relative to the cost of conventional sources of thermal energy is used to determine the thermal tariff.
d. An appropriate tariff for thermal energy is determined to be $0.054/kWh. Expressed in terms of hot water it is $8.36/m^3 when the source of energy is the low pressure well and $9.93/m^3 when the source of energy is separated brine.

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